Pixel Local Supports Updates: Data Transmission

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For UNM and UCSC

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Local Supports in the US

Seven activities in US-ATLAS ITk Pixels "Local Supports":

1. I-beam design, fabrication (LBNL)
2. Stave cooling services (ANL) – Update today
3. Stave cooling testing (SLAC)
4. End-of-stave interface card (SLAC)
5. Stave loading (SLAC)
6. Flex power+readout for outer layers (UNM) – Update today
7. Twisted pair for data transmission in innermost layers (UCSC) – Update today

These slides: some recent updates on flexes and twisted pair
More slides: Jimmy will show some slides on cooling at ANL

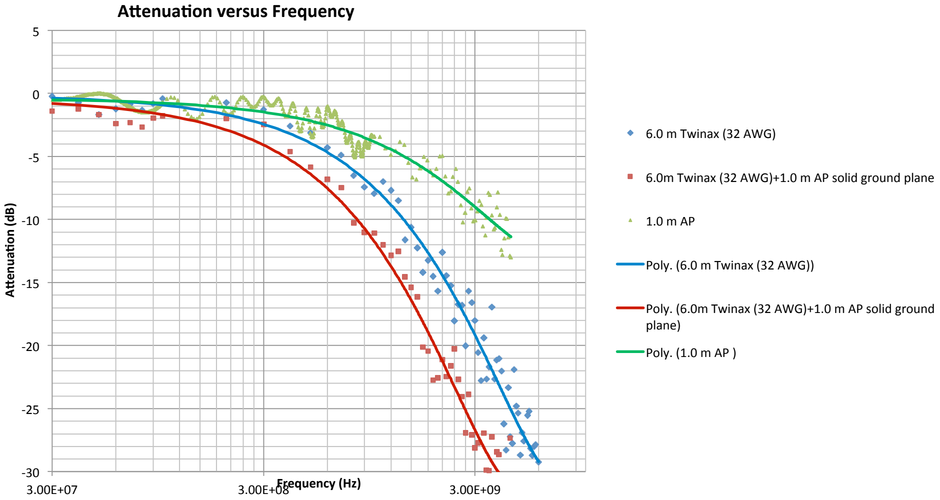
Kapton flex cable for high speed data transmission and support for modules

University of New Mexico,

Neil McFadden, Martin Hoeferkamp, Sally Seidel

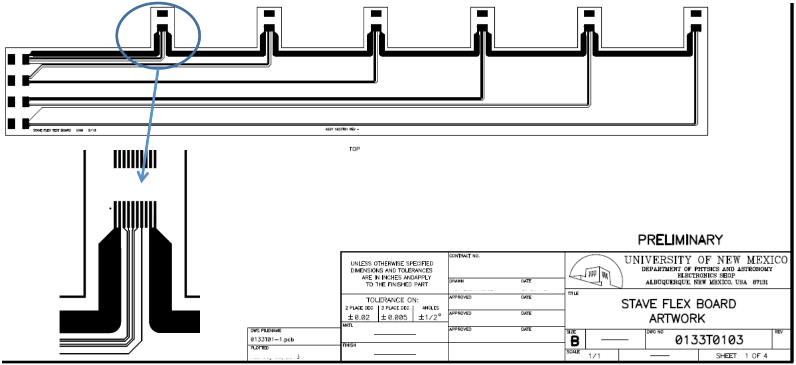
1.0 m Kapton (AP) Flex with cross hatched ground plane

- We have irradiated a 1.0 m Kapton flex with cross hatched ground plane in February at LANSCE in Los Alamos. The flex received a fluence of $6x10^{15}$ 800 MeV protons/cm^2.
- This flex prototype has a radiation length of 0.0160% when smeared over a 20 mm stave. It has achieved a bandwidth of 6.220 Gbps when all pre-amplifier conditions are applied, with an effective payload of 4.976 Gbps.
- To test for radiation damage to the adhesive between the layers of copper and Kapton, we have temperature cycled the flex from -40 C^o to +40 C^o. The temperature was held at the extreme points for 30 minutes. The impedance was measured continuously using time domain reflectometry. Any delamination will be apparent in the change of impedance along the length of the cable.
- The impedance of the unirradiated cable is 122±5 Ω. After four complete temperature cycles the average impedance of the irradiated flex was 123 ±6 Ω.
- The average impedance of the irradiated flex after four cycle is consistent with impedance of the unirradiated cable. Additional, we did not observe any fluctuations in impedance during the test, thus demonstrates that the adhesive is radiation hard.



- This plot compares attenuation versus frequency for a 1.0 m Kapton Cable, 6.0 m (32 AWG) twinax, and a 7.0 m hybrid cable.
- The twinax is the main contributor to the attenuation of the hybrid cable. Measurements for the hybrid cable were not possible after about 3 GHz because the signal was attenuated to much.
- Next we will do a BERT on the hybrid cable.

In Progress: Stave Flex



- We have been working on a design for a stave flex which will provide serial power, bias voltage, a temperature monitor, module control and high speed data transmission.
- This is a preliminary design. We are working on optimizing the routing to minimize the amount of unused space between modules, then the design will be stretched to the proper length.
- Future designs will include the proper number of module connections and/or interface to ANL quad module.

Twisted Pair

See Jason's slides from AUW

- **In brief**: propose to minimize material in innermost layers by using thin twisted wire pair (TWP) for on-stave data transmission, connecting to TwinAx at End-of-Stave for transmission to opto-boxes
- **Advantages**:
  - Low mass, reduced material in interaction region compared with other solutions
- **Challenges**:
  - Connection scheme at EoS needs to be developed (currently just soldering TWP and TwinAx together, doesn't scale)
  - Signal integrity degrades at high bandwidth (bit error rates and eye diagrams), need to deliver 5 Gbps after 8b/10b encoding

Test Program

Bit Error Rate Testers (BERT's)

	Xilinx ML-405 (Virtex-4)	Xilinx VC707 (Virtex-7)
Firmware	M. Kocian (SLAC)	Xilinx IBERT
Encoding	CML, 8b/10b	CML
Pre-emphasis	Adjustable	Adjustable
DFE	No	Optional

Testing different solutions:

- **TwinAx from FE to opto-boxes**:
  - Baseline solution shown by Martin Kocian, we also see good performance at high bandwidth ($>$ 6 Gbps raw rate with pre-emphasis and 8b/10b) for runs up to 6m
  - Longer runs (9.5 meters) achievable on Virtex-7, but not Virtex-4, differences under study
- **Hybrid Solution**: 1m TWP connected to 6m TwinAx
  - Good performance, payload rate up to 5 Gbps with no bit errors
  - **Next steps**: BERT tests using TWP + 9.5m TwinAx, connectorization

Inputs for Strips TDR

Strips TDR will include some content on Pixel plans

- Data transmission will be $\sim$1 page – Jason is organizing this
- Inputs mostly collected, need additional info from Annecy
- Making many assumptions
  - Full readout at L0 (1 MHz) for all modules, implies 5 Gbps needed for innermost layers
  - Separate down-links to each module, no multi-drop
  - Many of these to be revisited in coming months
- Almost ready to pass material to Tobias

Bonus

High-Bandwidth Electrical Data Transmission Services for Pixels

J. Nielsen, V. Fadeyev, A. Grillo, M. Hance, N. Johnson, B. Lin, F. Martinez-McKinney, J. Volk, M. Wilder

University of California, Santa Cruz

M. Hoeferkamp, N. McFadden, S. Seidel

University of New Mexico

M. Kocian, D. Nelson

SLAC National Accelerator Laboratory

AUW Pixel Readout and Electronics Meeting

18 April 2016

Introduction

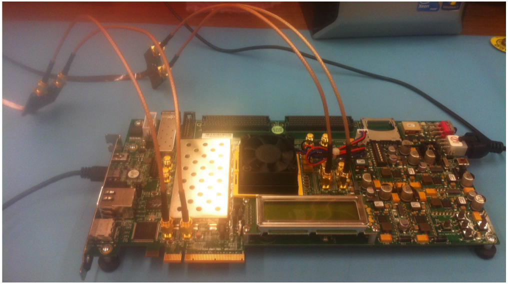
- Goal is to develop rad-hard / low-mass / high-speed solution for electrical data transmission from pixel FE to the opto-boards
  - Not only point-to-point data links, but also multi-drop clock/command
  - We assume a target bandwidth of up to 5 Gbps per link in the pixel barrels
  - See also Leyre Flores's talk later in today's session

- Following up on previous discussions about location of opto-electrical transition, we have recently investigated signal integrity in longer electrical systems, up to 9 m length
  - Take this as the "worst-case" scenario for electrical data transmission
  - Do the proposed solutions still function over this distance?

- Local synergy with similar studies of very long Kapton/Cu bus tapes on strip detector staves (but compare 640 Mbps to 5 Gbps)

Bit-Error Rate Testers

- Two bit-error rate testers for comparison and benchmarking:
  - Xilinx ML-405 (Virtex-4) with firmware developed by Martin Kocian.
  - Xilinx VC707 (Virtex-7) with Xilinx IBERT IP: up to 10 Gbps
- Both setups send/receive CML on two 50 Ω coaxial cables
  - Signals are terminated with 50 Ω to power rail, giving a voltage difference of 800 mV instead of 350 mV for LVDS
  - Each test uses just one BERT (no common-mode test between BERTs)
- Configurable parameters
  - 8b/10b encoding (ML-405)
  - Adjustable pre-emphasis
  - Decision Feedback Equalizer [DFE] (VC707): provides ultimate bandwidth, but may not be applicable to ITk



Twisted Wire Pairs and Twin-Axial Cable

- 36 AWG TWP is minimal-mass solution, even with 10-μm Al shield
  - However, previous tests showed max. length limit of 1 m length for error-free 5.0 Gbps transmission (4 m for 2.5 Gbps)
- Robust solution is twinax cable from M. Kocian et al.
  - The twinax solution (with drain wire to provide shield integrity) was initially tested at lengths up to 6 m, with direct connection to BERT

Twinax (6m, 28 AWG) directly soldered to BERT SMA cables					*Nov. 2015*
8b/10b	Pre-Emph.	Raw Rate (Gbps)	Errors	BER	Run Time
✗	✗	1.555	0	1.71×10^{-13}	1 hour
✓	✗	3.110	0	1.13×10^{-13}	1 hour
✗	✓	4.976	0	5.69×10^{-14}	1 hour
✓	✓	6.220	0	5.73×10^{-14}	1 hour

- Samples of twinax cable sent to collaborating institutes for testing
- But can mass be reduced further by using TWP in central region?

Hybrid TWP+Twinax Cables

- Custom 36 AWG twisted pair cables manufactured with 99 Ω impedance, matching 102 Ω for 28 AWG twinax cables
  - These twisted pair cables were tested to be rad-hard (1.5 x 10^{15} neq/cm^2)
- Join TWP and twinax directly -- no impedance matching required
- 1-m 36 AWG twisted pair + 6-m 28 AWG twinax is long enough to reach proposed PP1 transition from inner layers
- Testing shows 4.976 Gbps payload rate (correcting for 8b/10b) achieved over the 1+6-m hybrid cable

8b/10b	Pre-Emph.	Payload Rate (Gbps)	Errors	BER	Run Time
✗	✗	0.4976	4.57×10^4	1.93×10^{-8}	1 hour
✓	✗	1.9904	0	1.46×10^{-13}	1 hour
✗	✓	2.488	0	4.50×10^{-15}	20 hours
✓	✓	4.976	0	5.67×10^{-14}	1 hour

Tests of Long Twinax Solution

- Test of 9.5 m twinax cable connected directly to VC707 BERT inputs (newer BERT setup)
  - 31-bit pseudo-random bit pattern allows for unbalanced signal runs
  - Adjustable pre-emphasis amplitude, but no dynamic feedback equalization
  - BER results are really upper limits when no errors are seen

Pre-emph	Payload Rate (Gbps)	Errors	BER	Run Time
2.21 dB	5.00	0	1.07E-13	30 mins.
4.08 dB	6.25	1	9.26E-14	30 mins.
4.81 dB	6.25	4	3.75E-13	30 mins.

- According to these measurements, max. payload rate is 6.25 Gbps
  - Well above the 5 Gbps requirement for inner pixel layers, even without 8b/10b encoding!
  - Allows for more freedom in placing the opto-electrical transition

Tests of Long Twinax Solution

- Test of 9.5 m twinax cable connected directly to ML-405 BERT inputs (older BERT setup)
  - 31-bit pseudo-random bit pattern allows for unbalanced signal runs
  - Using baseline 17 dB pre-emphasis configuration

8b/10b	Pre-emph	Raw Rate (Gbps)	Errors	BER	Run Time
✘	✘	0.622	1	4.23E-10	30 mins.
✔	✘	1.555	0	4.45-13	30 mins.
✘	✔	3.110	0	1.77E-13	30 mins.
✔	✔	4.976	0	1.40E-13	30 mins.

- According to these measurements, max. payload rate is 4 Gbps (after 8b/10b decoding)
  - Still does not satisfy the 5 Gbps requirement for inner layers
- Results highlight possibility for confusing measurements

Twinax+TWP Comments and Conclusions

- Payload bandwidth is 6.25 Gbps
  - Error rate roughly 1E-13 for Virtex-7 gigabit transceivers
  - Investigating differences with respect to older BERT setup
- Preliminary conclusion: longer twin-ax run of 9 m seems feasible
  - Opto-electrical transition could move further away from pixel FE
  - Need to re-test this with a 1-m twisted-wire pair addition (minimal mass hybrid cable)
- Connectors are likely a key issue here at ultra-high frequencies